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Abstract

Source sector contributions to acidic wet deposition of H^+, NO_3^- and SO_4^{2-} in Ontario were investigated for the period 1981 to 1985. Three major sectors were defined for the monitoring sites, namely, the U.S. sector, the Ohio Valley sector and the Canada sector. To assign a sector of origin to each rain event, air parcel trajectories were computed and analysed.

Results indicate that the U.S. sector was the dominant contributor to the total annual wet deposition of H^+, NO_3^- and SO_4^{2-} in the border regions of Ontario, typically 80% for southwestern Ontario. For southeastern Ontario, the U.S. sector contribution was typically 50%, the Canada sector 10%, and the remaining 40% was unassigned. Mean volume weighted concentrations of the acidifying pollutants in rain originating from the United States were generally higher than in rain from Canada. The Ohio Valley sector contribution to the receptor sites in Ontario was often significant.

Over the five year period, the trend in concentrations of the acidifying pollutants in rain appears to be linked to changes in regional SO_2 emissions.

1. Introduction

Over the past several decades, the use of tall stacks, coupled with high emission levels of fossil fuel combustion products, has resulted in elevated atmospheric concentrations of several primary and secondary pollutants, such as the oxides of nitrogen and sulphur, throughout the industrialized world. This in turn has resulted in significant increases in acidity levels from wet and dry deposition of the pollutants and is generally referred to as the acid rain phenomenon.

Elevated levels of acidity have been recorded in precipitation over Ontario, Canada during the past decade. Most of southern and central Ontario experience more that 20 kg/ha/yr of SO_4^{2-} in precipitation (Chan et al.,1984). Such levels have been found to be potentially harmful to water bodies (MOE, 1983). Indeed, there are a considerable number of lakes in the Muskoka area of central Ontario which are seriously damaged because of the acidic deposition.

In the past years, several investigations have linked southerly air flows into Ontario to high atmospheric concentrations of several pollutants, and high acidity in precipitation (Chung, 1978; Shenfeld et. al., 1979; Heidorn, 1981; Kurtz et. al., 1984; Yap and Kurtz, 1984; and Tang et. al., 1986).

Deposition in Ontario is influenced by several source areas. Some of these are in Ontario, for example, the Sudbury smelter and the highly industralized areas of Metropolitan Toronto-Hamilton and Windsor-Sarnia. Other significant source regions include the highly industrialized Ohio Valley in the United States. Fig. 1 shows the major source regions of SOx and NOx in eastern North America.

Detailed understanding of source-receptor relationships requires information on source emissions, dispersion/ transport, chemical transformation and deposition at the receptor. As complete information of all these aspects is never available, a number of complementary approaches are often employed. One such approach is the use of air parcel trajectory sector analysis to investigate source-receptor linkage. In this study, this method of analysis, with its inherent limitations, was used to assess the relative contributions of source sectors in Canada and the United States to the acidic wet deposition in Ontario for the five year period 1981-1985.

2. Method

2.1 Wet Deposition Network

The Air Resources Branch of the Ministry of the Environment (MOE) established in mid 1980 and 1981 province-wide networks to monitor both wet and dry deposition (inferred from air concentration measurements), respectively (Chan et al., 1982, 1984)

Data for the present analysis came from four MOE daily precipitation sampling sites, namely, Dorset, Longwoods, Charleston Lake and Fernberg (See Fig.1). In particular, the wet deposition data for H^+, NO_3^- and SO_4^{2-} were used.

The collected MOE samples were analysed in the Laboratory Services Branch of the Ministry and were subjected to stringent validation/screening criteria such as sample integrity checks.

2.2 Trajectory Model

Neglecting acceleration, representative horizontal winds in the atmospheric boundary layer were obtained from the surface and 850-mb geostrophic winds, with modifications for surface frictional effects. This task was accomplished with an objective analysis scheme using 3-h synoptic weather data from approximately 300 stations in a 30x30 grid system (grid length 127 km) for the surface level and using 12-h height fields on a 11 x 11 grid system (grid length 381 km) for the 850-mb level. To obtain back trajectories of air parcels arriving at a specific location, the surface wind vectors and the 850-mb wind vectors were integrated with backward time steps over the required periods, up to 2-3 days. Trajectories derived in this manner are in general agreement with low-level tetroon observations (Peterson, 1966)

In this study, the possible source regions for wet deposition at the four sites were primarily inferred from the modified surface geostrophic winds. This type of trajectory analysis has been used previously to relate acidic deposition to pollutant source region (e.g. Kurtz et al., 1984).

2.3 Source Sectors

The four receptor sites are located at Dorset, Longwoods (near London), Charleston Lake (near Kingston) and Fernberg (near Thunder Bay) respectively. For each station, different source sectors were defined based on the emission density areas as depicted in Fig.1. As the primary aim of this study was to assess the relative contributions of the United States and Canada to acidic deposition in Ontario, the first two sectors that were defined for each site (except Dorset) enveloped either the whole of Canada or the whole of the

United States. For Dorset, it was not possible to define such sectors as the site is not in the U.S.-Canada border region. The defined U.S. and Canada sectors for the relevant receptor sites are shown in Fig. 2.

To evaluate the importance of the Ohio Valley region on the deposition in Ontario, an Ohio Valley sector was defined for each receptor. The sectors in each instance encompassed most of the emission sources in the Ohio Valley Region (Fig. 3).

2.4 Analysis

By fitting the back trajectories of each rain event into one of the defined sectors, a source sector was assigned to each of the events. If there were multi trajectories for an event, the rain event was assigned to the sector in which most of the trajectories fell. Where some of the trajectoiries crossed sector boundaries because of trajectory curvature, the source sector was designated unknown/unassigned. Thus, it was not possible to assign a sector to each rain event. In some instances, the unknown sector was very significant.

The mean volume-weighted concentrations of H^+, NO_3^- and SO_4^{2-} in precipitation and the total wet deposition of these pollutants at the 4 monitoring sites were calculated for each year. Subsequently, the total deposition and mean concentration which could be assigned to the source sectors were computed. From this information, the relative contribution of each sector to the total wet deposition at each site was calculated for each year.

3. Results

Wet deposition data for 1980 were incomplete and therefore were excluded from this study. In addition, the Fernberg data were very limited so only a partial analysis was conducted on the data for the years 1984 and 1985. The main analysis was performed on the data for Dorset, Longwoods and Charleston Lake for the five years 1981-1985.

The results of the analysis, comparing the volume weighted concentrations in the wet deposition and the total loading originating from the Ohio Valley sector with those originating from the non-Ohio Valley sector are found in Appendix 1. The results of the comparison of deposition associated with United States sector and Canada sector are given in Appendix II.

In order to compare the results for different years with each other, the relative contribution of the various sectors to the total loading was calculated for each year. (Table 1).

4. Discussion

4.1 Trajectory Accuracy and Limitations

The accuracy of air parcel trajectory models is influenced by the simplifying assumptions that are inherent in them. In the model used in this study it is assumed that the air parcel remains constant on one level. In a study comparing isentropic, isobaric and constant height trajectory models, it was found that the isentropic model yielded the highest degree of accuracy (Kuo et al., 1985). Another study concluded that models with assumptions similar to the ones used in this study work relatively well under steady weather conditions, but show large inaccuracies near frontal movements (Artz et al., 1985).

This study focuses on wet deposition and as precipitation often occurs near frontal zones, inaccuracies in the trajectories due to frontal movements must be taken into account. When, as in this study, large source areas are involved, these inaccuracies are minimized because even a large deviation of the calculated trajectory from the true trajectory will not significantly influence the choice of sector to which the rain event is assigned.

The fact that trajectories of air parcels undergo curvature and cross sector boundaries is an inherent limitation to this study. For both the Charleston Lake and Fernberg sites, this resulted in approximately 40% of the events being assigned to the unknown sector.

4.2 Deposition Trend

As can be seen in Appendix I and II, the volume of precipitation and the number of precipitation events at the monitoring stations are variable over the years. These differences are mainly caused by the fact that weather patterns change from year to year.

Because of meteorological fluctuations, especially in precipitation volumes over the years, conclusions about trends in the total wet deposition at the four monitoring sites can only be tentative. Therefore, it is more meaningful to focus on differences in the volume-weighted mean concentration of pollutants over the years.

The volume-weighted mean concentrations of H^+, NO_3^- and SO_4^{2-} in precipitation at Dorset declined over the first three years. This same trend can be found in the Longwoods and Charleston Lake mean concentrations. Only the mean H^+

concentration in the Longwoods precipitation seems to have increased over those same three years.

To make it possible to compare the trends in wet deposition levels with the emission changes over the years the total emissions of SO_2 within the different sectors were estimated (Table 2). Only the emissions within a 1,000 km radius from the receptor site were taken into account, 1,000 km being an average length of an 48 hour trajectory.

SO_2 emissions have generally decreased in all the sectors between 1981 and 1983 and increased thereafter. A similar pattern can be seen in the concentration data of the acidic pollutants in rain (Fig.4). For the same period NO_x emission changes have been less pronounced than those for SO_2. Overall, NO_x emissions have remained at a relatively constant level. It can thus be generalized that the changes of acidifying emission have a noticeable impact on the deposition chemistry. A recent study (Dillon et al., 1988) indicates that the decrease in SO_2 emissions in eastern North American in the past decade was strongly correlated with a decrease in bulk deposition rates and concentrations of SO_4^{2-} and H^+ in precipitation in central Ontario.

4.3 Dorset

The Ohio Valley sector at Dorset also includes the Hamilton, Toronto and Windsor areas in Ontario. However, since the Ontario areas only contribute 10% to the total emissions in this sector, the results still illustrate the relative importance of the Ohio Valley region.

The fact that even in 1983 more than 30% of the total deposition of H^+, NO_3^- and SO_4^{2-} can be assigned to the

relatively small Ohio Valley sector does mean that this region significantly influences deposition in the Dorset area.

Since the total amount of deposition which could not be assigned to a specific sector increased over the years, a definite trend in any of the contributions cannot be firmly established.

4.4 Longwoods

At Longwoods the comparison between the United States and Canada was more revealing. Over the study period, the relative contribution from the United States sector to the total deposition was approximately 80%. At the same time, the contribution of the Canada sector was approximately 5%. The overwhelming contribution of the U.S. sector to the sulphate wet deposition at Longwoods can be seen in Fig.5.

On the average, 50% of the deposition originating from the United States comes from the Ohio Valley sector. The mean concentration in rain originating from the Ohio Valley is not much higher than that originating from the whole of the United States. The high emission levels in the Ohio Valley would lead one to expect a larger difference. However, from these results it cannot be concluded that the Ohio Valley contributes more significantly than the rest of the United States to the deposition in the Longwoods area.

4.5 Charleston Lake

At Charleston Lake, the relative contribution from the United States sector to the total deposition was approximately 50% (with fluctuations from year to year) whereas the contribution of the Canada sector was about 10%. A significant portion of the deposition (40%) was of unknown origin.

4.6 Fernberg

Based on the limited data at Fernberg, it would appear that 50% of the acidic deposition was associated with the U.S. sector and about 10% attributed to the Canada sector. As in the case of Charleston Lake, a significant portion of the deposition (40%) was of unknown origin.

5. Conclusions

Meteorological variability, especially differences in the amounts of precipitation, have had a strong influence on the results. As a result, only limited conclusions about changes in the relative contributions from the different sectors over the years can be inferred. Extending this study to include dry deposition results would probably overcome this problem to a certain extent, and would also make it possible to arrive at more definite conclusions about the total deposition in Ontario.

At some of the receptor sites there was always a relatively high number of rain events that could not be assigned to any sector of origin. Such rain events contributed considerably to the wet deposition at the monitoring stations, sometimes up to 40%. These high percentages are often caused by high concentrations of pollutants in this rain and the mean concentrations in this rain were often higher than in any of the defined sectors.

This study has found that rain originating from the United States has a higher mean concentration of acidifying pollutants than rain originating from Canada. Furthermore, it can be stated that the contribution of the United States to the acidic wet deposition in southern Ontario is considerable, in the border regions, amounting to as much as 80%. These results are also consistent with and collaborate the earlier study by Tang et. al. (1986).

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Table 1 Total annual wet deposition and the relative contribution from various sectors to this total at different receptor sites, 1981 to 1985

DORSET

Year	Poll.	Total Annual Wet Deposition n	Depo.		Ohio V. Sector n	Depo.(%)	Non Ohio V. Sector n	Depo.(%)
1981	H+	57	53956.2	ueq/m2	23	54.9	26	35.8
	NO3	114	346.3	mg/m2	32	49.4	58	31.3
	SO4	113	2338.0	mg/m2	31	52.9	58	31.5
1982	H+	87	59830.1	ueq/m2	27	41.8	35	28.5
	NO3	144	422.1	mg/m2	34	35.6	67	33.0
	SO4	143	2390.1	mg/m2	34	40.1	67	26.0
1983	H+	74	51459.6	ueq/m2	18	33.0	41	36.0
	NO3	113	336.0	mg/m2	23	31.4	67	38.5
	SO4	113	1865.5	mg/m2	23	32.3	67	33.5
1984	H+	73	54249.7	ueq/m2	27	46.0	18	18.6
	NO3	122	390.2	mg/m2	36	45.4	38	17.6
	SO4	122	2118.9	mg/m2	36	52.2	38	15.2
1985	H+	103	49837.1	ueq/m2	18	24.8	42	28.1
	NO3	150	497.9	mg/m2	20	21.3	60	34.3
	SO4	149	2258.8	mg/m2	20	24.2	59	23.7

LONGWOODS

Year	Poll.	Total Annual Wet Deposition n	Depo.		U. S. Sector n	Depo.(%)	Ohio V. Sector n	Depo.(%)	Canada Sector n	Depo.(%)
1981	H+	27	21936.1	ueq/m2	17	64.0	11	25.2	7	15.6
	NO3	101	500.5	mg/m2	70	79.0	36	36.5	18	8.3
	SO4	101	3189.6	mg/m2	70	77.1	36	37.8	18	7.7
1982	H+	62	43389.7	ueq/m2	48	80.0	29	46.8	7	9.6
	NO3	94	383.9	mg/m2	66	73.5	34	35.6	11	9.8
	SO4	94	2294.331	mg/m2	66	76.2	33	39.5	11	8.5
1983	H+	41	41196.6	ueq/m2	34	86.5	22	51.0	1	3.6
	NO3	78	289.3	mg/m2	63	86.0	37	49.8	2	1.9
	SO4	79	2169.0	mg/m2	64	88.5	38	50.7	2	0.8
1984	H+	31	56975.1	ueq/m2	27	95.4	18	85.1	1	2.1
	NO3	69	386.2	mg/m2	52	84.9	35	64.9	3	3.6
	SO4	69	2489.9	mg/m2	52	88.2	35	71.2	3	2.3
1985	H+	78	47933.1	ueq/m2	54	78.6	33	54.0	4	0.6
	NO3	125	506.7	mg/m2	76	74.8	47	46.0	10	2.1
	SO4	124	2798.8	mg/m2	75	76.4	46	51.0	10	1.5

Table 1 (continued)

CHARLESTON LAKE

Year	Poll.	Total Annual Wet Deposition n	Depo.		U. S. Sector n	Depo.(%)	Ohio V. Sector n	Depo.(%)	Canada Sector n	Depo.(%)
1981	H+	54	63492.0	ueq/m2	24	49.1	12	25.5	16	23.6
	NO3	114	376.9	mg/m2	39	43.5	26	28.9	45	29.4
	SO4	113	2362.2	mg/m2	39	36.3	25	29.5	45	24.5
1982	H+	37	25145.9	ueq/m2	18	61.9	11	35.7	5	5.3
	NO3	87	342.7	mg/m2	43	64.2	16	17.1	17	10.1
	SO4	88	2172.3	mg/m2	43	64.2	16	20.2	17	8.9
1983	H+	50	33909.5	ueq/m2	36	71.7	8	20.8	6	8.9
	NO3	81	262.7	mg/m2	53	71.2	12	14.8	16	13.8
	SO4	81	1479.5	mg/m2	53	72.1	12	19.2	16	15.5
1984	H+	19	14339.7	ueq/m2	9	55.5	4	30.8	3	8.9
	NO3	80	303.4	mg/m2	38	50.4	14	22.8	18	25.1
	SO4	80	1584.6	mg/m2	38	52.2	14	24.6	18	22.7
1985	H+	10	7794.6	ueq/m2	N/A		4	36.8	1	5.7
	NO3	93	347.3	mg/m2	30	30.1	17	19.8	15	15.7
	SO4	93	1790.3	mg/m2	30	30.1	17	26.7	15	11.2

FERNBERG

Year	Poll.	Total Annual Wet Deposition n	Depo.		U. S. Sector n	Depo.(%)	Ohio V. Sector n	Depo.(%)	Canada Sector n	Depo.(%)
1984	H+	N/A			N/A		N/A		N/A	
	NO3	51	113.0	mg/m2	18	42.0	3	9.9	11	7.7
	SO4	51	629.1	mg/m2	18	39.4	3	7.2	11	7.5
1985	H+	N/A			N/A		N/A		N/A	
	NO3	41	122.6	mg/m2	17	54.8	5	23.7	11	17.6
	SO4	41	651.9	mg/m2	17	50.7	5	28.4	11	18.6

* U.S. sector includes the Ohio Valley sector
n = amount of rain events in a group
depo = total annual deposition at the receptor site
depo% = percentage of the total deposition originating from a sector

Table 2 Annual SO_2 emissions within the defined sectors out to 1000km from the receptor for the period 1981 to 1985

RECEPTOR	SECTOR	EMISSIONS (MILLION TONNES) 1981	1982	1983	1984	1985
DORSET	OHIO VALLEY	7.5	7.2	6.4	7.3	6.9
	CANADA	1.9	1.3	1.5	1.9	1.9
LONGWOODS	OHIO VALLEY	10.6	10.0	9.4	10.4	10.0
	U. S. A.	17.1	16.2	15.0	16.2	15.2
	CANADA	1.9	1.3	1.5	1.9	1.9
CHARLESTON LAKE	OHIO VALLEY	7.7	7.3	6.6	7.5	7.1
	U. S. A.	13.8	13.1	12.0	13.1	12.1
	CANADA	1.9	1.3	1.5	1.9	1.9

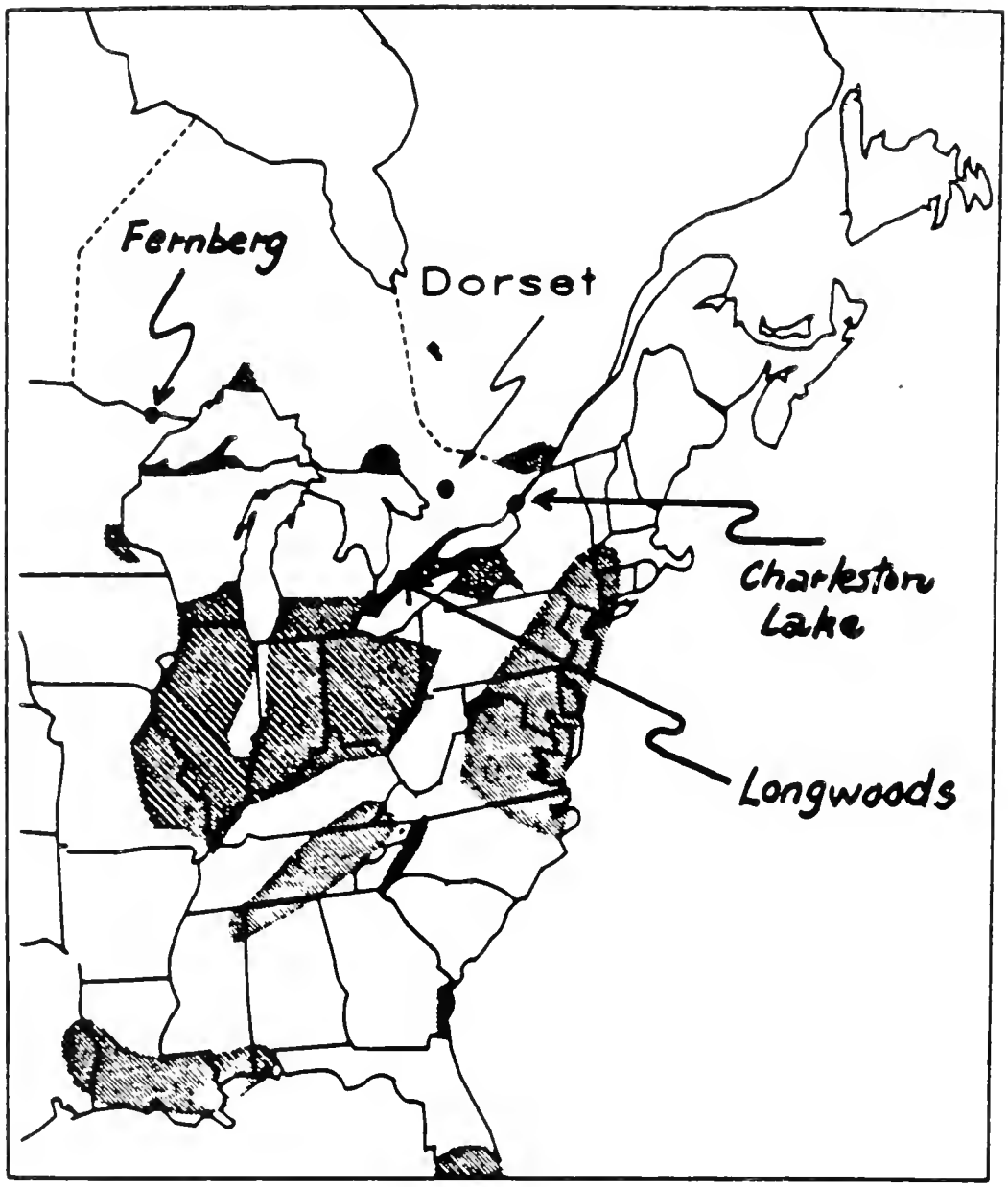

Fig. 1 Location of the study sites showing approximate areas (shaded) of high SO_2 and NO_x emissions (modified from Atmospheric Environment Service, Environment Canada)

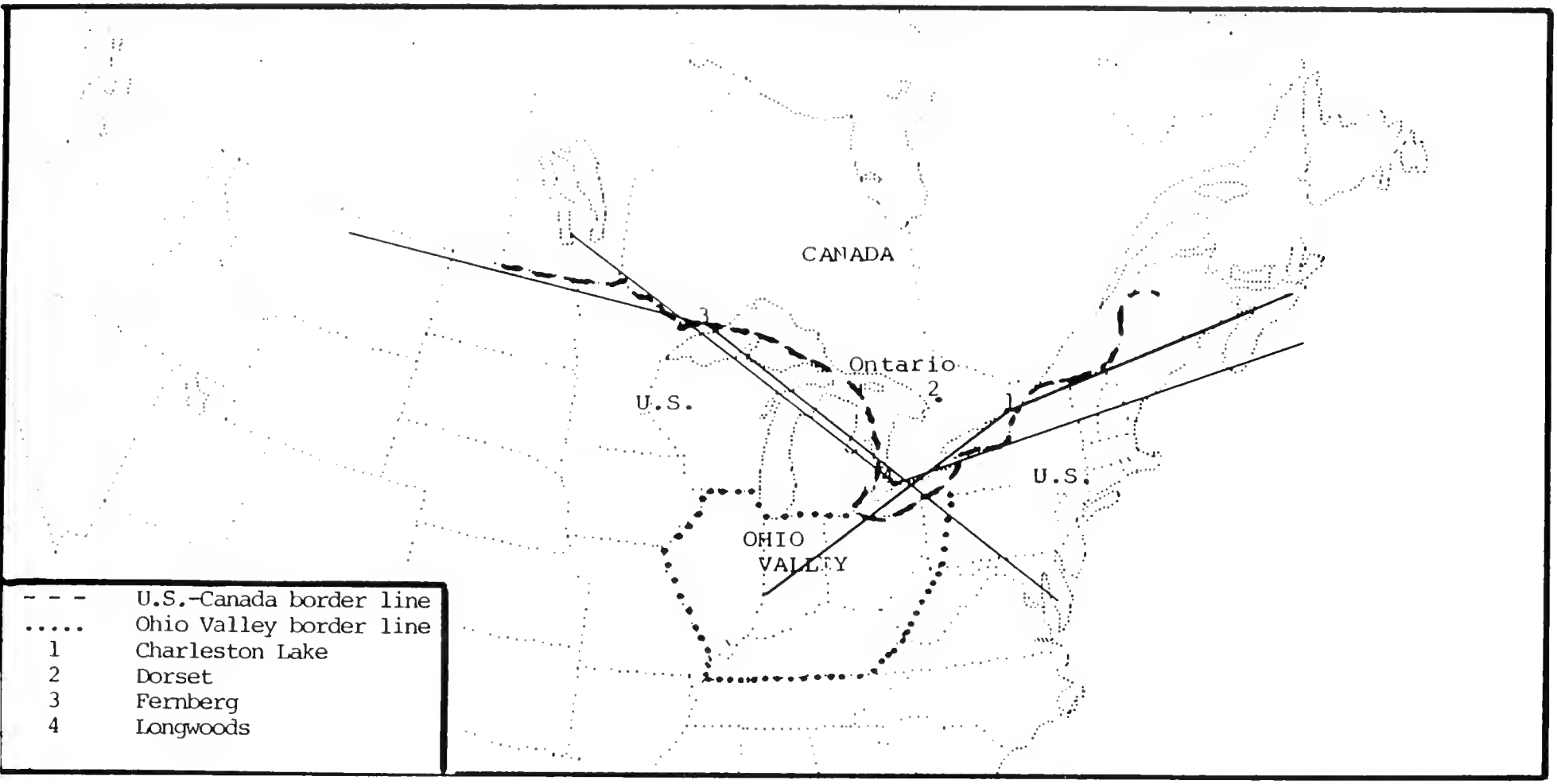

Fig. 2 United States-Canada Sectors

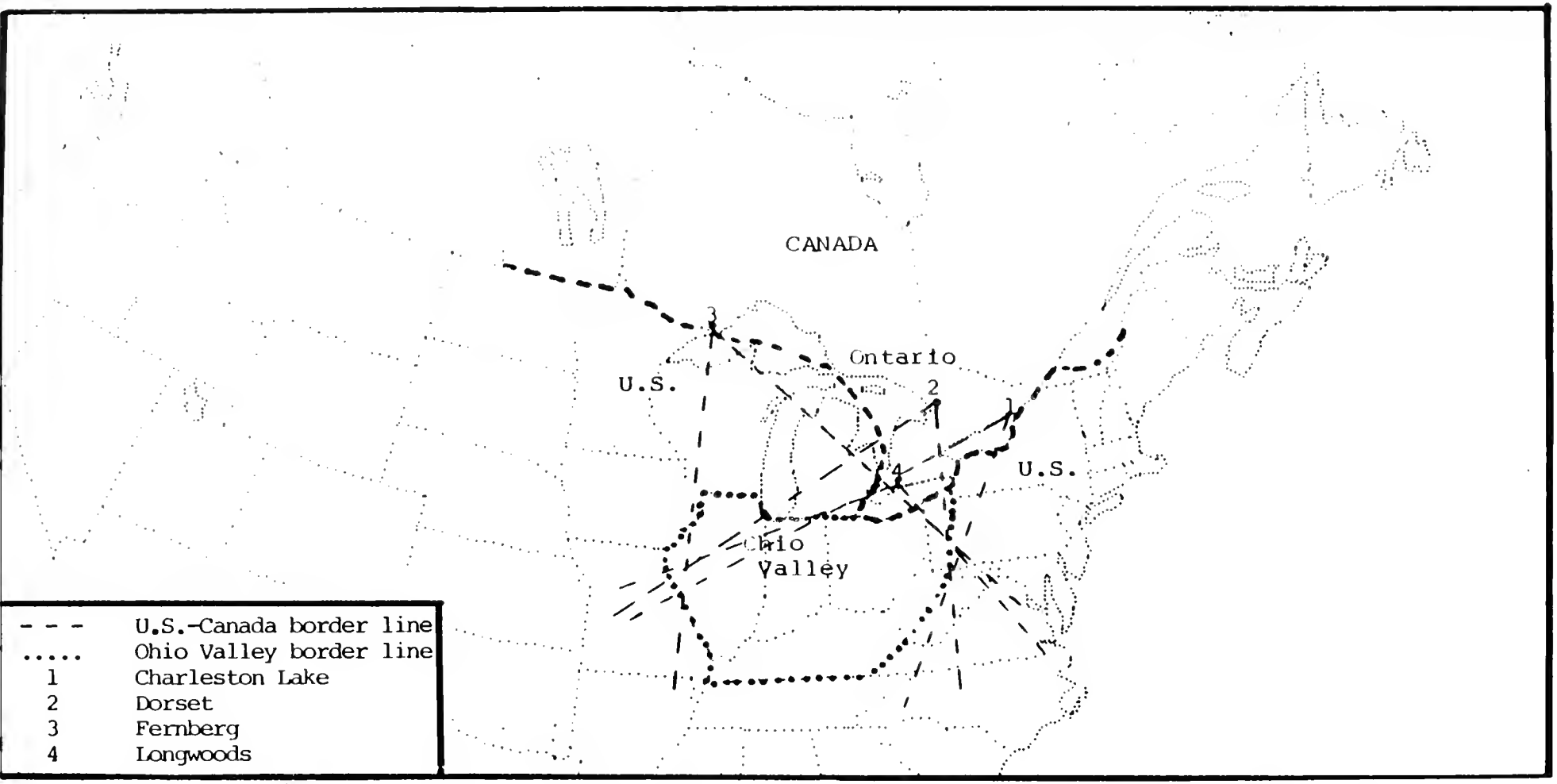

Fig. 3 Ohio Valley-Non Ohio Valley sectors

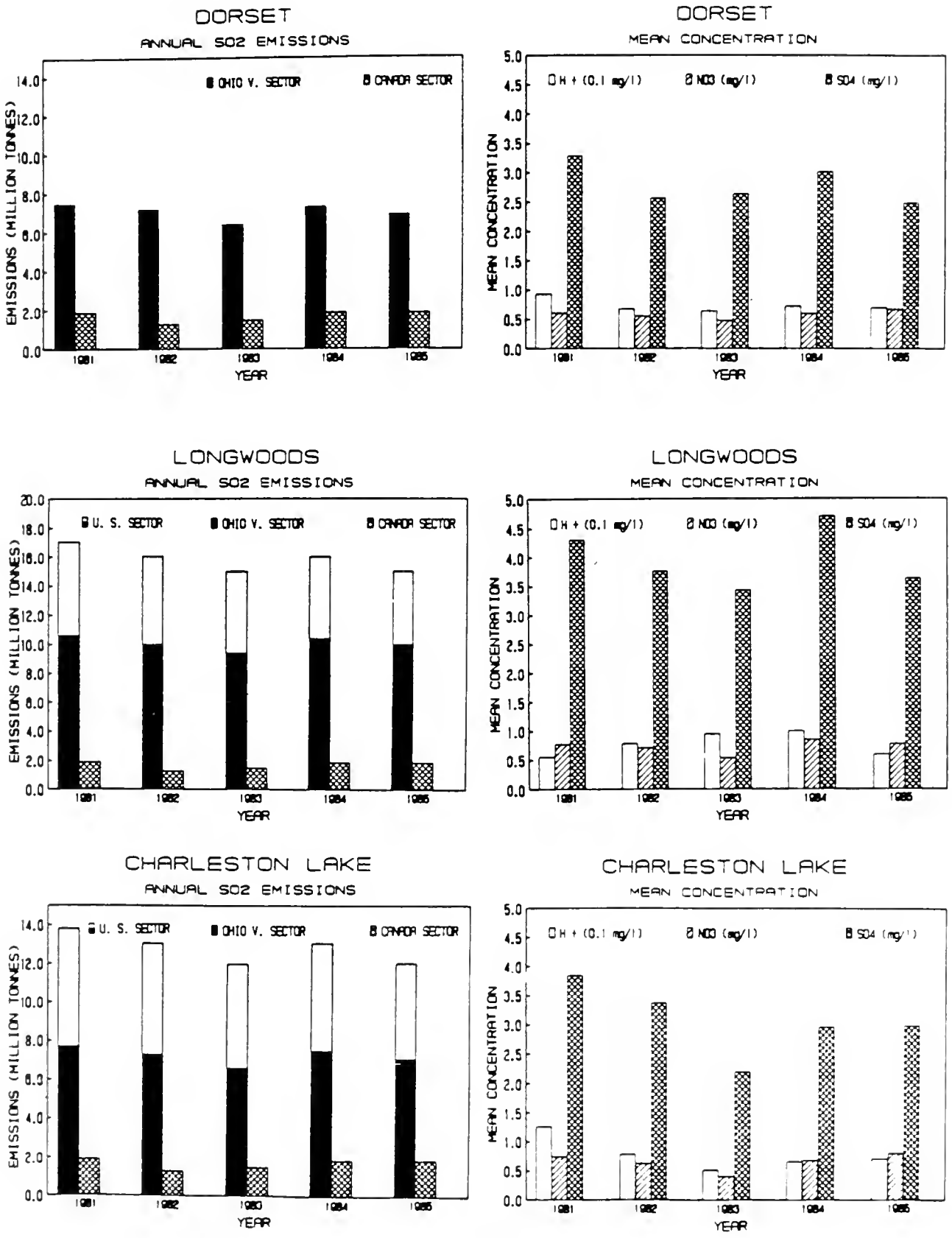

Fig. 4 Trends in sector SO_2 emissions and volume-weighted mean concentrations of H^+, and NO_3^- and SO_4^{-2} at Dorset, Longwoods and Charleston Lake

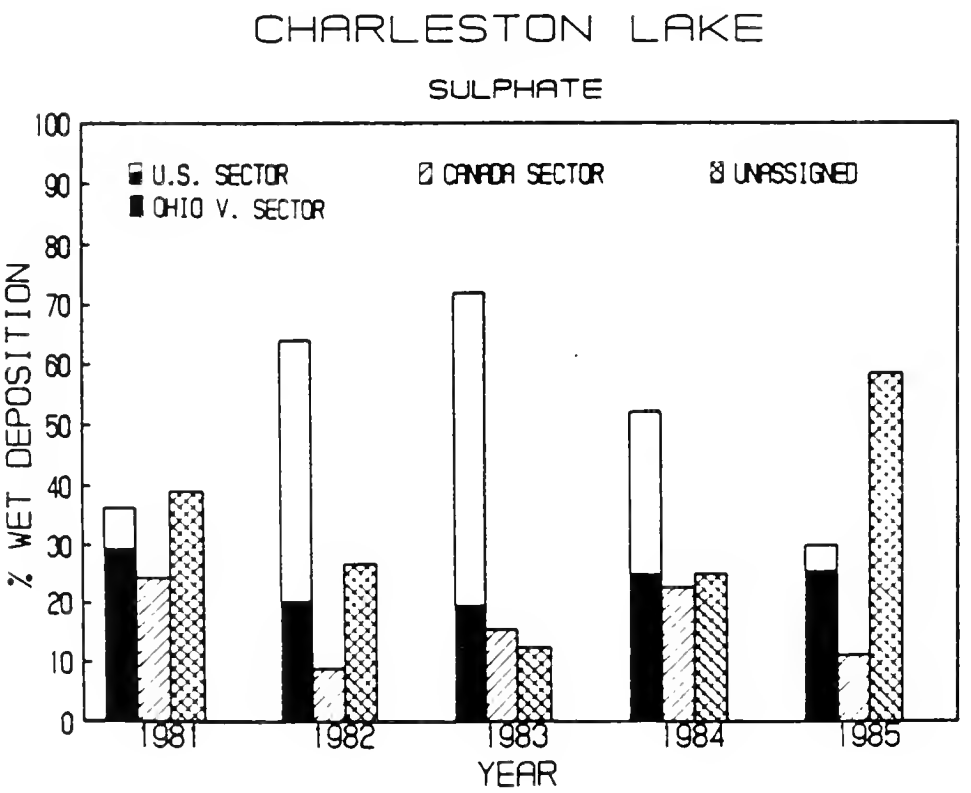

Fig. 5 Wet deposition of sulphates and associated U.S. and Canada sectors for Longwoods and Charleston

APPENDIX I

Comparison of the Volume weighted concentrations in the wet deposition and total loading originating from the OHIO Valley sector with those originating from NON OHIO Valley sectors.

Sector	= Region where the air parcels come from.
n	= Amount of rain events from the sector.
Mean Conc.	= Mean concentration in the rain events from the sector.
Total Loading	= Total wet deposition originating from the sector.
Ohio V.	= Ohio Valley region (see figure 2).
Other sect.	= Non Ohio Valley region (see figure 2).
Unknown	= Rain events originating from unknown region.
Summary	= All the rain events for the year.
Gauge Depth	= Amount of rain originating from the sector.
NO3	= Nitrate
SO4	= Sulphate

!

DORSET H+

Year	Sector	n	Mean Conc. ueq/l	Total Loading ueq/m2	Gauge Depth mm
1981	Ohio V.	23	121.1	29627.3	289
	Other Sect.	26	77.2	19324.3	232
	Unknown	8	65.9	5004.6	96
	Summary	57	93.3	53956.2	619
1982	Ohio V.	27	79.9	25067.1	341
	Other Sect.	35	50.1	17065.6	353
	Unknown	25	80.6	17697.2	246
	Summary	87	68.1	59830.2	940
1983	Ohio V.	18	85.2	17035.7	238
	Other Sect.	41	45.1	18521.6	436
	Unknown	15	92.8	15902.2	204
	Summary	74	64.5	51459.6	878
1984	Ohio V.	27	78.0	24949.9	395
	Other Sect.	18	56.8	10070.7	170
	Unknown	28	78.2	19229.1	249
	Summary	73	72.9	54249.7	814
1985	Ohio V.	18	72.5	12363.7	192
	Other Sect.	42	60.4	13991.7	289
	Unknown	43	77.7	23481.8	411
	Summary	103	69.8	49837.1	892

DORSET NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	32	0.803	171.2	311
	Other Sect.	58	0.464	108.3	299
	Unknown	24	0.713	66.8	145
	Summary	114	0.612	346.3	755
1982	Ohio V.	34	0.573	150.5	347
	Other Sect.	67	0.497	139.3	408
	Unknown	43	0.627	132.4	299
	Summary	144	0.554	422.1	1054
1983	Ohio V.	23	0.637	105.4	248
	Other Sect.	67	0.347	129.4	501
	Unknown	23	0.725	101.2	218
	Summary	113	0.483	336.0	967
1984	Ohio V.	36	0.686	177.0	411
	Other Sect.	38	0.348	68.5	222
	Unknown	48	0.740	144.7	282
	Summary	122	0.602	390.2	914
1985	Ohio V.	20	0.848	106.2	179
	Other Sect.	60	0.641	170.6	348
	Unknown	70	0.655	221.1	521
	Summary	150	0.675	497.9	1048

DORSET SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	31	5.00	1235.9	311
	Other Sect.	58	2.36	738.1	299
	Unknown	24	3.30	364.0	145
	Summary	113	3.29	2338.0	745
1982	Ohio V.	34	1.68	621.0	347
	Other Sect.	67	3.47	959.6	408
	Unknown	42	3.27	809.2	299
	Summary	143	2.57	2390.1	1054
1983	Ohio V.	23	3.36	603.3	248
	Other Sect.	67	1.74	625.1	501
	Unknown	23	4.59	637.2	218
	Summary	113	2.65	1865.5	967
1984	Ohio V.	38	3.65	1106.7	411
	Other Sect.	36	1.76	321.9	222
	Unknown	48	3.54	690.3	982
	Summary	122	3.02	2118.9	914
1985	Ohio V.	20	3.98	547.5	179
	Other Sect.	59	1.69	535.2	346
	Unknown	70	2.74	1176.1	521
	Summary	149	2.49	2258.8	1046

LONGWOODS H+

Year	Sector	n	Mean Conc. ueq/l	Total Loading ueq/m2	Gauge Depth mm
1981	Ohio V.	11	51.3	5522.6	104
	Other Sect.	13	57.5	14228.1	211
	Unknown	3	64.1	2185.5	31
	Summary	27	55.7	21936.1	345
1982	Ohio V.	29	89.9	20290.6	303
	Other Sect.	19	59.0	10173.9	209
	Unknown	14	82.3	12925.2	208
	Summary	62	78.7	43389.7	720
1983	Ohio V.	22	92.7	21022.5	264
	Other Sect.	11	85.1	12125.5	163
	Unknown	8	114.0	8048.7	75
	Summary	41	94.8	41196.6	502
1984	Ohio V.	18	105.5	48477.5	348
	Other Sect.	3	110.8	2912.2	25
	Unknown	10	86.3	5585.4	89
	Summary	31	99.9	56975.1	462
1985	Ohio V.	33	67.1	25884.8	392
	Other Sect.	9	31.6	2422.2	78
	Unknown	36	59.6	19626.1	354
	Summary	78	59.5	47933.1	824

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LONGWOODS NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	36	0.717	182.5	322
	Other Sect.	42	0.762	163.1	332
	Unknown	23	0.896	155.0	212
	Summary	101	0.777	500.5	867
1982	Ohio V.	34	0.526	136.5	333
	Other Sect.	36	0.769	126.4	255
	Unknown	24	0.897	121.0	230
	Summary	94	0.714	383.9	818
1983	Ohio V.	37	0.564	144.0	357
	Other Sect.	26	0.527	95.9	231
	Unknown	15	0.503	49.3	138
	Summary	78	0.540	289.3	726
1984	Ohio V.	35	O.723	250.8	470
	Other Sect.	6	0.870	30.7	38
	Unknown	28	1.015	104.7	181
	Summary	69	0.854	386.2	688
1985	Ohio V.	47	0.847	232.9	444
	Other Sect.	22	0.634	55.0	118
	Unknown	56	0.771	218.9	414
	Summary	125	0.776	506.7	976

LONGWOODS SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	36	4.43	1204.6	322
	Other Sect.	42	3.70	988.7	332
	Unknown	23	5.20	966.3	212
	Summary	101	4.30	3189.6	867
1982	Ohio V.	33	3.43	905.4	328
	Other Sect.	37	3.24	582.3	255
	Unknown	24	5.02	806.5	230
	Summary	94	3.76	2294.3	813
1983	Ohio V.	38	3.71	1099.8	358
	Other Sect.	25	2.90	688.7	229
	Unknown	16	3.62	380.6	144
	Summary	79	3.43	2169.0	731
1984	Ohio V.	35	4.34	1774.0	470
	Other Sect.	6	3.67	147.5	38
	Unknown	28	5.36	568.3	181
	Summary	69	4.70	2489.9	688
1985	Ohio V.	46	4.42	1427.1	419
	Other Sect.	22	1.93	145.2	118
	Unknown	56	3.65	1226.5	414
	Summary	124	3.63	2798.8	951

CHARLESTON LAKE H+

Year	Sector	n	Mean Conc. ueq/l	Total Loading ueq/m2	Gauge Depth mm
1981	Ohio V.	12	117.6	16206.8	122
	Other Sect.	27	114.9	25028.5	296
	Unknown	15	151.9	22257.7	225
	Summary	54	125.8	63492.0	643
1982	Ohio V.	11	84.9	9001.2	107
	Other Sect.	16	87.4	10968.8	175
	Unknown	10	56.4	5175.9	122
	Summary	37	78.3	25145.9	403
1983	Ohio V.	8	67.7	7047.2	92
	Other Sect.	36	43.4	20167.4	498
	Unknown	6	80.0	6694.8	70
	Summary	50	51.7	33909.4	661
1984	Ohio V.	4	125.6	4414.2	100
	Other Sect.	6	47.0	2694.1	39
	Unknown	9	52.9	7231.3	129
	Summary	19	66.4	14339.7	268
1985	Ohio V.	4	59.9	2869.2	56
	Other Sect.	2	39.7	749.0	20
	Unknown	4	98.7	4176.3	48
	Summary	10	71.4	7794.6	124

CHARLESTON LAKE NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	26	0.867	108.9	188
	Other Sect.	62	0.592	160.3	402
	Unknown	26	0.997	107.6	250
	Summary	114	0.747	376.9	840
1982	Ohio V.	16	0.622	58.6	116
	Other Sect.	48	0.586	148.8	367
	Unknown	23	0.699	99.3	237
	Summary	87	0.630	342.7	720
1983	Ohio V.	12	0.692	38.8	82
	Other Sect.	55	0.298	168.5	655
	Unknown	14	0.591	55.4	113
	Summary	81	0.407	262.7	850
1984	Ohio V.	14	1.011	69.3	78
	Other Sect.	38	0.634	134.3	362
	Unknown	28	0.601	99.8	238
	Summary	80	0.688	303.4	679
1985	Ohio V.	17	0.939	68.6	215
	Other Sect.	28	0.781	93.0	199
	Unknown	48	0.778	185.7	334
	Summary	93	0.808	347.3	747

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CHARLESTON LAKE SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Ohio V.	25	5.42	699.5	181
	Other Sect.	62	3.22	879.8	402
	Unknown	26	3.85	782.9	250
	Summary	113	3.85	2362.2	833
1982	Ohio V.	16	4.06	438.8	116
	Other Sect.	48	2.64	912.4	367
	Unknown	24	4.42	821.1	243
	Summary	88	3.38	2172.3	725
1983	Ohio V.	12	4.17	283.4	82
	Other Sect.	55	1.58	877.3	655
	Unknown	14	3.00	318.9	113
	Summary	81	2.21	1479.5	850
1984	Ohio V.	14	4.77	390.0	78
	Other Sect.	38	2.73	649.3	362
	Unknown	28	2.40	545.3	238
	Summary	80	2.97	1584.6	679
1985	Ohio V.	17	3.70	477.7	215
	Other Sect.	28	2.47	382.9	199
	Unknown	48	3.06	929.6	334
	Summary	93	3.00	1790.3	747

FERNBERG NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1984	Ohio V.	3	0.610	11.2	50
	Other Sect.	20	0.179	25.2	145
	Unknown	28	0.361	76.7	285
	Summary	51	0.304	113.0	480
1985	Ohio V.	5	0.412	29.0	76
	Other Sect.	21	0.329	52.2	208
	Unknown	15	0.339	41.4	147
	Summary	41	0.342	122.6	432

FERNBERG SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1984	Ohio V.	3	2.23	45.5	50
	Other Sect.	20	1.00	142.2	145
	Unknown	28	1.66	441.4	285
	Summary	51	1.44	629.1	480
1985	Ohio V.	5	2.06	184.9	76
	Other Sect.	21	1.70	262.3	208
	Unknown	15	1.61	204.7	147
	Summary	41	1.71	651.9	432

APPENDIX II

Comparison of deposition associated with U.S. sector and Canada sector.

LONGWOODS H+

Year	Sector	n	Mean Conc. ueq/l	Total Loading ueq/m2	Gauge Depth mm
1981	Canada	7	38.8	3418.7	69
	U. S.	17	60.0	14042.6	207
	Unknown	3	71.0	474.7	69
	Summary	27	55.7	21936.1	345
1982	Canada	6	54.1	4194.3	88
	U. S.	48	84.0	34844.6	560
	Unknown	8	65.6	4380.7	72
	Summary	62	78.7	43389.7	720
1983	Canada	1	275.4	1487.3	5
	U. S.	34	92.6	35615.3	444
	Unknown	6	77.5	4094.0	33
	Summary	41	94.8	41196.6	502
1984	Canada	1	169.8	1188.8	7
	U. S.	27	101.0	54347.3	418
	Unknown	4	66.3	1439.1	37
	Summary	31	99.9	56975.1	462
1985	Canada	4	18.6	264.1	21
	U. S.	54	61.0	37668.0	643
	Unknown	20	63.7	10001.1	160
	Summary	78	59.5	47933.1	824

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LONGWOODS NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Canada	18	0.775	41.7	110
	U. S.	70	0.800	395.3	625
	Unknown	13	0.655	63.5	132
	Summary	101	0.777	500.5	866
1982	Canada	11	0.522	37.7	97
	U. S.	66	0.667	282.5	630
	Unknown	17	1.012	63.7	91
	Summary	94	0.714	383.9	818
1983	Canada	2	0.560	5.5	10
	U. S.	63	0.554	248.9	639
	Unknown	13	0.469	35.0	76
	Summary	78	0.540	289.3	726
1984	Canada	3	1.163	13.8	10
	U. S.	52	0.818	327.8	607
	Unknown	14	0.924	44.7	71
	Summary	69	0.854	386.2	688
1985	Canada	10	0.505	10.7	31
	U. S.	76	0.825	379.0	725
	Unknown	39	0.748	117.1	219
	Summary	125	0.776	506.7	976

LONGWOODS SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Canada	18	3.69	244.1	110
	U. S.	70	4.40	2459.8	625
	Unknown	13	4.60	485.7	132
	Summary	101	4.30	3189.6	867
1982	Canada	11	2.46	195.3	97
	U. S.	66	3.56	1747.1	627
	Unknown	17	5.39	351.9	91
	Summary	94	3.76	2294.3	813
1983	Canada	2	1.80	18.1	10
	U. S.	64	3.61	1919.1	645
	Unknown	13	2.80	231.8	76
	Summary	79	3.43	2169.0	731
1984	Canada	3	4.45	56.4	10
	U. S.	52	4.60	2195.2	607
	Unknown	14	5.12	238.4	71
	Summary	69	4.70	2489.9	688
1985	Canada	10	2.24	43.3	31
	U. S.	75	3.92	2137.3	700
	Unknown	39	3.44	618.3	219
	Summary	124	3.63	2798.8	951

CHARLESTON LAKE H+

Year	Sector	n	Mean Conc. ueq/l	Total Loading ueq/m2	Gauge Depth mm
1981	Canada	16	146.6	14975.9	151
	U. S.	24	108.4	31158.3	323
	Unknown	14	132.0	17357.8	169
	Summary	54	125.8	63492.0	643
1982	Canada	5	136.6	1353.9	25
	U. S.	18	73.5	15565.7	209
	Unknown	14	63.6	8226.3	169
	Summary	37	78.3	25145.9	403
1983	Canada	6	39.9	3027.9	73
	U. S.	36	52.8	24314.9	485
	Unknown	8	55.3	6566.6	103
	Summary	50	51.7	33909.4	661
1984	Canada	3	26.5	1274.4	61
	U. S.	9	91.6	7955.3	109
	Unknown	7	51.0	5109.9	98
	Summary	19	66.4	14339.7	268
1985	Canada	1	31.6	442.7	14
	U. S.		N/A	N/A	N/A
	Unknown		N/A	N/A	N/A
	Summary	10	71.4	7794.6	124

CHARLESTON LAKE NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Canada	45	0.781	110.8	220
	U. S.	39	0.616	164.1	401
	Unknown	30	0.867	102.0	219
	Summary	114	0.747	376.9	840
1982	Canada	17	0.434	34.6	76
	U. S.	43	0.746	220.1	382
	Unknown	27	0.568	88.0	263
	Summary	87	0.630	342.7	720
1983	Canada	16	0.429	36.3	110
	U. S.	53	0.390	187.0	623
	Unknown	12	0.451	38.5	117
	Summary	81	0.407	262.7	850
1984	Canada	18	0.909	76.3	150
	U. S.	38	0.748	153.0	292
	Unknown	24	0.428	74.2	237
	Summary	80	0.688	303.4	679
1985	Canada	15	0.913	54.0	92
	U. S.	30	0.691	104.6	306
	Unknown	48	0.849	188.8	350
	Summary	93	0.808	347.3	747

CHARLESTON LAKE SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1981	Canada	45	3.35	581.3	220
	U. S.	39	4.19	1096.3	401
	Unknown	29	4.15	684.6	212
	Summary	113	3.85	2362.2	833
1982	Canada	17	2.59	192.5	76
	U. S.	44	4.02	1393.5	387
	Unknown	27	2.84	586.2	263
	Summary	88	3.38	2172.3	725
1983	Canada	16	2.38	229.3	110
	U. S.	53	2.12	1067.3	623
	Unknown	12	2.37	183.9	117
	Summary	81	2.21	1479.5	850
1984	Canada	18	2.89	360.2	150
	U. S.	38	3.63	827.2	292
	Unknown	24	1.98	397.2	237
	Summary	80	2.97	1584.6	679
1985	Canada	15	2.06	200.0	92
	U. S.	30	3.44	682.5	306
	Unknown	48	3.02	907.8	350
	Summary	93	3.00	1790.3	747

FERNBERG NO3

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1984	Canada	11	0.115	8.7	70
	U. S.	18	0.352	47.5	189
	Unknown	22	0.360	56.8	221
	Summary	51	0.304	113.0	480
1985	Canada	11	0.275	21.6	120
	U. S.	17	0.447	67.2	161
	Unknown	13	0.263	33.8	151
	Summary	41	0.342	122.6	432

FERNBERG SO4

Year	Sector	n	Mean Conc. mg/l	Total Loading mg/m2	Gauge Depth mm
1984	Canada	11	0.61	46.9	70
	U. S.	18	1.64	247.6	189
	Unknown	22	1.68	334.6	221
	Summary	51	1.44	629.1	480
1985	Canada	11	1.46	121.2	120
	U. S.	17	2.05	330.8	161
	Unknown	13	1.47	199.9	151
	Summary	41	1.71	651.9	432